Evaluation of Shear Creep Response of Recycled Asphalt Shingle Mixtures

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ABSTRACT: In this research, shear creep response of recycled asphalt shingles (RAS) stabilized with self-cementing fly ash (FA) and RAS mixed with bottom ash (BA) were investigated. Systematic constant stress consolidated-drained triaxial tests were conducted on compacted RAS:BA mixtures and fly ash stabilized RAS at different deviator stress levels, temperatures and confining pressures. Creep rupture was observed at deviator stress levels higher than 80% of the deviator stress at failure. Strain rate also increases as an exponential function of temperature. In designing side slopes of highway embankments containing RAS, the maximum deviator stress obtained from the triaxial compression test should be reduced by at least 20% to prevent the creep rupture. Construction of embankment fills containing RAS is recommended during warm seasons to minimize long term creep deformation of the embankment side slopes.

INTRODUCTION

Recycled asphalt shingles (RAS) are produced by grinding tear-off roof shingles or manufacture shingle scraps. Approximately 12 million Mg of asphalt shingle waste is produced per year in the U.S., of which only 10 to 20% is reused (Turley 2011). Soleimanbeigi (2012) and Soleimanbeigi et al. (2012) suggested that RAS mixed with granular materials such as bottom ash (BA) or stabilized by self-cementing fly ash become viable for use in high volume structural fill applications such as highway embankment fills. Since RAS particles contain viscous asphalt binder, the shear strain at the particle contacts is expected to increase under applied sustained deviator stress and make the compacted RAS mixture susceptible to shear creep deformation and possible rupture. In this study, consolidated drained triaxial tests under constant axial stress were conducted to evaluate shear creep response of the compacted RAS:BA mixture and stabilized RAS. The tests were performed under different deviator stress levels, temperatures and confining pressures to more precisely simulate field conditions.

CREEP MODEL

The creep response is represented by a relationship between creep strain and time. The simplified empirical model of Singh and Mitchell (1968) is used to characterize creep response of the compacted RAS:BA mixtures and fly ash-stabilized RAS. The model is represented by:

$$\dot{\varepsilon} = Ae^{\bar{\alpha}\bar{D}}\left(\frac{t_1}{t}\right)^m \tag{1}$$

where $\dot{\varepsilon}$ is the strain rate ($\dot{\varepsilon} = \Delta\varepsilon/\Delta t$), $\bar{D}$ is the deviator principal stress level ($\bar{D} = \sigma_d/\sigma_{df}$, where σ_d is the applied principal stress difference and σ_{df} is the principal stress difference at failure), t_1 is an arbitrary reference time and t is the elapsed time after loading, $\bar{\alpha}$ is the slope of the log $\dot{\varepsilon}$ versus $\bar{D}$ curves, A is the y intercept of the log $\dot{\varepsilon}$ versus $\bar{D}$ curve at $\bar{D} = 0$ at a given t_1, and m is the slope of the log $\dot{\varepsilon}$ versus log t curve and is defined as creep rate parameter. The m < 1.0 indicates susceptibility of material to creep and possible rupture (Mitchell and Soga 2005).

MATERIALS

RAS particles are plate-like, irregular in shape, highly angular and have rough surface texture. According to Unified Soil Classification System (USCS), RAS is classified as equivalent of well graded sand. The maximum dry unit weight (γ_{dmax}) of RAS and BA are 11.3 kN/m^3 and 15 kN/m^3, respectively. The γ_{dmax} of the compacted RAS:BA mixture with 25% RAS content is 13.5 kN/m^3. Stabilized RAS with 20% self-cementing fly ash has the γ_{dmax} of 13.7 kN/m^3. The compaction curves of RAS mixtures are not sensitive to water content. These specific mixing ratios were obtained from a testing program aimed at bringing RAS compressibility to acceptable levels (Soleimanbeigi et al. 2012).

EXPERIMENTAL PROGRAM

The specimens included the compacted RAS:BA mixtures with BA content of 75% and stabilized RAS with 20% self-cementing fly ash. Each sample was compacted at optimum water content (w_{opt}) and 95% of standard Proctor γ_{dmax} in a split mold with 74-mm diameter and 148-mm height. Each compacted RAS:FA specimen was cured in a 100% humidity room in a sealed condition for 28 days. To monitor the volume change, each specimen was backpressure-saturated according to ASTM D 4767. Following the consolidation at confining pressure (σ'_3) of 70 kPa, creep tests were conducted by applying different stress levels, $\bar{D}$, ranging from 0.60 to 0.95 on the specimens. To evaluate the effect of temperature, a temperature-controlled triaxial creep test cell was developed to conduct shear creep tests at typical field temperatures ranging from 5 °C to 35 °C. The principal stress differences at failure (σ_{df}), were determined from the results of CD triaxial compression tests on the compacted RAS:BA mixtures and stabilized RAS. To investigate the effect of confining pressure, creep tests were conducted on the compacted RAS:BA mixtures compressed at different confining pressures ranging from 35 kPa to 280 kPa.

RESULTS

Creep Response of RAS:BA Mixture

Fig. 1 (a) shows the variation of log axial strain rate ($\dot{\varepsilon}$) with $\log t$ at different stress levels. The axial strain rate increases with stress level and creep rupture occurs for specimens at $\bar{D}$ > 0.80. The creep rupture is also identified when the axial strain rate increases with time in the log $\dot{\varepsilon}$-log t curve and is represented by time to rupture, t_r, corresponding to minimum strain rate, $\dot{\varepsilon}_{min}$. The continued creep test at $\bar{D}$=0.8 for 6 weeks shows that the axial strain linearly increases with log t without any sign of rupture. The variation of log t_r with $\bar{D}$ shown in Fig. 1 (b) indicates that time to rupture in log scale nonlinearly increases with decreasing stress level. The nonlinear relationship suggests an asymptote to an upper yield strength of approximately 0.80 for the compacted RAS:BA mixture. Below the upper yield strength, the material is not expected to experience creep rupture under the applied deviator stress. At $\overline{D} \leq 0.80$, the log $\dot{\varepsilon}$ linearly decreases with log t indicating that the compacted RAS:BA mixture follows a classical creep behavior similar to soils (Mitchell and Soga 2005). The average best-fit m is 0.91 which indicates the creep susceptibility and possible rupture of the compacted RAS:BA mixture. The characterized creep model for the compacted RAS:BA mixture is therefore represented by:

$$\dot{\varepsilon} = 0.022e^{4.80\overline{D}}\left(\frac{1}{t}\right)^{0.91} \tag{2}$$

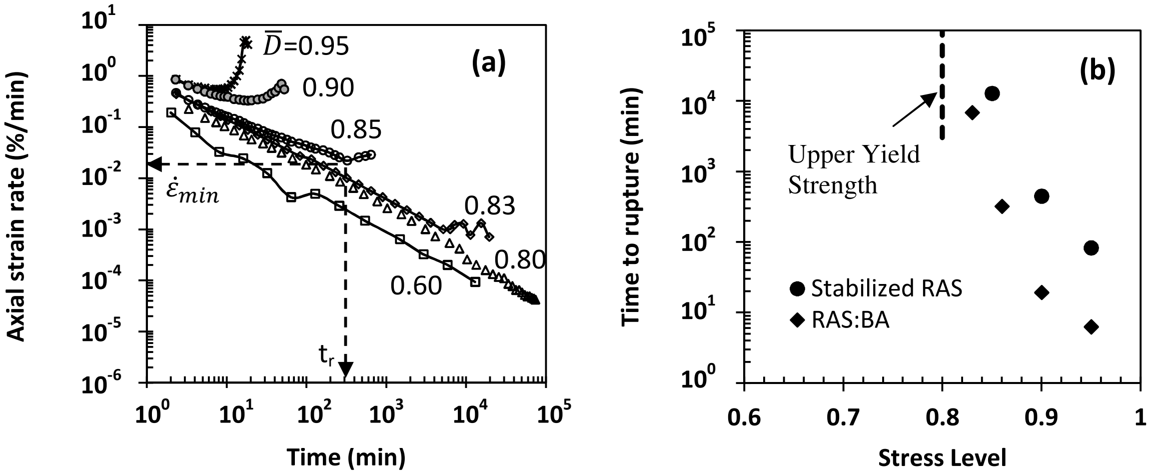

FIG. 1. Axial strain rate versus time for the compacted RAS:BA mixture (a) and time to rupture versus stress level for RAS:BA and fly ash stabilized RAS (b).

Effect of Temperature

The results of deviator creep tests on the compacted RAS:BA mixture show that axial strain rate in logarithmic scale linearly increases with temperature (Soleimanbeigi 2012). The slopes of the lines are identical at different time after temperature change and is defined as coefficient of thermal creep denoted by $R_{T\varepsilon}$:

$$\frac{dln\dot{\varepsilon}}{dT} = R_{T\varepsilon} \tag{3}$$

By substitution of Eq. (1) to Eq. (3) and after a simple mathematical manipulation, the effect of temperature is appeared in the Singh and Mitchell (1968) creep model:

$$\dot{\varepsilon} = Ae^{\overline{\alpha}\overline{D}+R_{T\varepsilon}\Delta T}\left(\frac{t_1}{t}\right)^{m} \tag{4}$$

Eq. (4) indicates that deviator strain rate of the compacted RAS:BA mixture exponentially increases with increasing temperature. To limit the strain rate, Soleimanbeigi (2012) suggested since the viscosity of asphalt binder in RAS particles is reduced at higher temperature, if the embankment fills containing RAS be constructed during summer, the majority of compression occurs during construction. This way, the strain rate will be reduced to 3.6×10^{-6} %/min which is comparable to strain rate of compacted sand (1.7×10^{-6} %/min), hence limiting the creep of the RAS:BA mixture. Fig. 2 (a) shows how the strain rate for a specimen that experienced a thermal cycle is reduced compared to a specimen at isothermal condition.

Effect of Confining Pressure

Fig. 2 (b) shows the log $\dot{\varepsilon}$ versus log *t* at $\bar{D}$=0.9 compressed at different σ'_3. The time to creep rupture and the creep rate parameter *m* consistently increases with increasing σ'_3. Increasing σ'_3 changes the stress-strain behavior of the compacted RAS:BA specimen from strain softening to strain hardening and the volumetric behavior from dilative to compressive. It appears that at higher σ'_3, the asphalt binder in RAS particles deforms to reduce void spaces in the specimen. Since asphalt binder is incompressible; at reduced void space, the specimen exhibits lower axial strain under a given *t* and $\bar{D}$. Although not included in Eq. (1), σ'_3 appears to affect the axial strain rate of the compacted RAS:BA mixture.

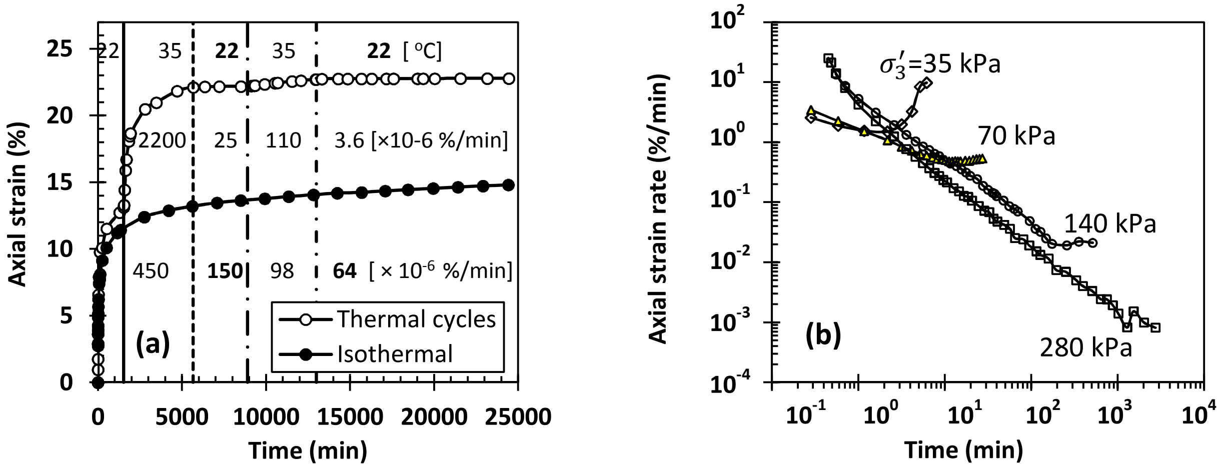

FIG. 2. Effect of temperature (a) and confining stress (b) on strain rate

Creep Response of Fly Ash-Stabilized RAS

The axial strain rate increases with stress level and creep rupture occurs at $\bar{D} \geq 0.85$ as shown in Fig. 3 (a). At $\bar{D} \leq 0.80$ the strain rate reduces log-linearly with time with no indication of creep rupture after five weeks. Fig. 1 (b) shows that the time to rupture is nonlinearly increases with decreasing stress level and represents an asymptote to an upper yield stress level of approximately 0.80. The average best-fit *m* over $\bar{D} \leq 0.8$ is 0.78 for t < 10000 min. However, the continued creep test showed that *m* increases to 1.25 over t > 10000 min. The reason is possibly attributed to reduction in void ratio over time. Fig. 3 (b) shows that at $\bar{D} \geq 0.8$, despite initial compression of the specimen, volumetric strain increased and material exhibits dilative behavior at the initiation of creep rupture. However at $\bar{D} \leq 0.8$, the material exhibits contractive behavior and the void ratio is reduced over time from 0.4 to 0.36 during the test. Since asphalt binder and sand particles in the mixture are incompressible, reduction in void ratio will reduce compressibility of the specimen which subsequently reduces the strain rate. The creep model for stabilized RAS is therefore characterized by:

$$\dot{\varepsilon} = 0.032e^{4.60\bar{D}}\left(\frac{1}{t}\right)^{m}, \begin{cases} \mathrm{m} = 0.78 \text{ for t } < \ 10000 \text{ min} \\ \mathrm{m} = 1.25 \text{ for t } > \ 10000 \text{ min} \end{cases} \tag{5}$$

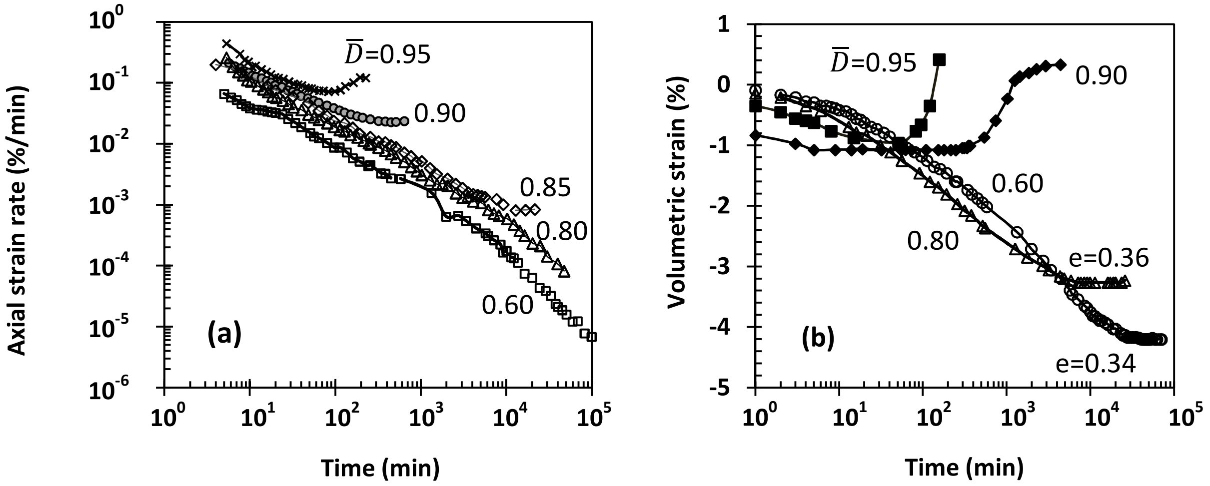

FIG. 3. Axial strain rate versus time (a) and volumetric strain versus time (b) for the stabilized RAS:FA

CONCLUSIONS

Creep rupture should be a concern when using compacted RAS:BA mixtures or stabilized RAS as structural fill. To minimize potential of creep rupture, the design engineer should keep the maximum shear stress to at least 20% below the compressive strength when designing slopes of the highway embankments or retaining structures to make sure creep rupture is unlikely to occur during lifetime of the fill. To minimize the long term settlement rate, construction of the embankment containing RAS is recommended during summer. Recycled asphalt shingles can be used in construction of highway embankment fills limiting their intrinsic compressibility by mixing with other less compressible granular materials or stabilizing with binders such as fly ash. Such high-volume use not only resolves the disposal problem of the material but also helps provide a more sustainable roadway construction using recycled materials.

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